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# Trigger Strategies and Processing for DUMAND

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JUN 14 1993
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## ABSTRACT

The DUMAND (Deep Underwater Muon and Neutrino Detector) experiment must recognize signals generated by a few single muon tracks per minute in the presence of ~50 KHz of random single-photoelectron pulses on each phototube (~12 MHz for the entire 216-tube array), originating from $^{40}$K beta-decay. To this end we have developed a four-level trigger system. The first level is a custom-built circuit board with the primary function of digitally identifying near-neighbor time coincidences, which serve as logical elements to define more elaborate global trigger conditions. The second and third levels are implemented in digital signal processors and general purpose microcomputers resident in a VME crate. The upper level is a cluster of computer workstations. An outline of the design, with an emphasis on the first level, is presented.

## 1. INTRODUCTION

The DUMAND II array will deploy 216 phototubes with 15-inch hemispherical photocathodes in the deep Pacific Ocean near Hawaii. Calculations tested by the deployment of similar phototubes at the site (Babson *et al.*) lead us to anticipate single-photon counting rates of 50 KHz on each tube from Cherenkov photons emitted by beta particles from the decay of $^{40}$K.

The predominant signal of physical interest is the traversal of the array by a single muon. This will typically generate signals on from 8 to 20 phototubes in the entire array, falling within a time window of up to 1.0$\mu$s for a muon that traverses the longest dimension of the array. Some of the muon-generated pulses are likely to be above the single photoelectron level. Traversals of this sort are expected at a rate of several per minute. Since any given 1.0$\mu$s window will ordinarily contain

* For a complete list of DUMAND collaborators and a description of the DUMAND array, see "Update on the Status of Dumand II," C.M. Alexander *et al.*, in these Proceedings

nearly as many random single photon pulses as are generated by a typical muon, fluctuations in this background will frequently be comparable to the count on a track. While track-fitting algorithms that make use of the 1.8ns rms time resolution of the phototubes can easily eliminate most of this background, a trigger strategy based solely on the global count rate in the array will generate an unacceptable rate of false triggers for off-line analysis.

For this and other reasons, we decided at an early stage in the design of DUMAND to digitize all signals in the ocean and pipeline them to shore via optical fibers, in order to permit the maximum flexibility in the design and operation of hardware and software capable of recognizing potentially interesting events. Another feature of the design that is significant for trigger strategy is the spacing of the phototubes on the nine vertical strings on which they will be deployed. This will permit us to trigger on coincidences of near-neighbor phototubes within time windows much shorter than $1.0\mu s$. It was in large measure this consideration that led to the choice of a $10m$ vertical spacing. while the horizontal spacing between strings will be on the order of $40m$.

Even within the shorter time windows permitted by close vertical spacing of the phototubes, the random twofold coincidence rate would still be on the order of tens of KHz per string, far too large to serve as a usable trigger. Thus we are obliged to combine several such coincidences, possibly accompanied by information on pulse amplitudes, to form a variety of recognizable trigger conditions that will allow us to detect muons with high efficiency without having to archive for off-line analysis an unmanageable sample of random data. Our benchmark goal is to reduce the random trigger rate below 1.0Hz.

To achieve this goal, we have designed a four-level system. The first level is implemented in custom-built circuit boards that make extensive use of programmable logic devices. The function of this level is to recognize interesting potential trigger conditions at the single-string level. The next two levels are implemented on commercially available digital signal processors (DSPs) and general-purpose microprocessors. Their function is to search for higher-level trigger conditions that may involve several strings. All three of these levels are on circuit boards coresident in a single VME crate. The fourth level is a networked cluster of computer workstations.

In addition to single particle tracks, the trigger logic must recognize large hadronic or electromagnetic cascades in or near the volume of the array, and large increases in signal over a time scale appropriate for the passage of a nonrelativistic particle through the array.

Each pulse on a phototube is digitized in two 40-bit words, one of which gives the start time of the pulse and the other its stop time, with a

1.0ns least count. The time difference between these words is determined by the pulse amplitude with a roughly logarithmic relationship. To extend the dynamic range of the system, additional words may be generated by exceptionally large pulses. Though each string of phototubes digitizes according to its own free-running clock, when pulses arrive on shore a time stamp is added every microsecond to enable correlations of times between strings.

Additional backgrounds may be generated from time to time by bioluminescent organisms that come close to one of the phototubes (Webster *et al.*). These tend to saturate the phototube for a time period on the order of 0.1 to 1.0s. They are flagged on the ocean floor at the individual phototubes, and have no significant effect on the trigger logic.

## 2. THE FIRST LEVEL PROCESSOR (FLP)

The functions of this level, implemented on a single 9U VME board that serves one string of 24 phototubes and two calibration lasers, are as follows:

1. Translate time information into pulse amplitude;
2. Identify near-neighbor double and triple coincidences;
3. Record counting rates of the individual phototubes;
4. Detect and report error conditions in the data stream.

At the heart of each board is a four-port memory cache (only three ports are used in the initial design) that holds a 256 microsecond window of data, continuously updated. Two ports communicate with higher levels of the system while a third serves the key logic elements, which reside on permanently-programmed logic chips, Actel model 1240. These chips incorporate 4000 elementary gates into about 400 independent cells that perform the coincidence searches, time translations, and error detection functions. Each chip serves two phototubes, including those on board the laser calibration modules, for a total of 13 chips per board.

The system recognizes both double and triple coincidence conditions by absolute time differences, either on contiguous tubes or with one intervening tube that does not fire. The coincidence windows are adjustable, and vary with the separation of the tubes. When such a condition is recognized, a flag is passed to the digital signal processor (DSP) board described in the next section. Data is passed to this board both through private communications channels and via the VME bus.

The entire system is conservatively designed to operate on a basic 140ns cycle time; we anticipate that under actual operating conditions, it will be capable of somewhat faster performance.

## 3. HIGHER LEVELS OF THE SYSTEM

When the FLP recognizes a coincidence, it passes an interrupt to a DSP, along with a flag that identifies the microsecond in which the signal occurred. At present we employ a system with three DSPs per string. The DSPs are Texas Instruments Corp. Model C30, with a 33 MHz clock, mounted on a "Ranger" board furnished by the Image and Signal Processing Corp. We believe that the three DSPs are a conservative design, but a fourth DSP can be added to the Ranger board if first-level trigger rates are higher than anticipated.

Software in the DSP identifies higher order trigger conditions, including coincidences of higher than threefold multiplicity, coincidences where one partner has a signal above an amplitude threshold, and a large amplitude sum for the entire string. In initial tests of the software, it has taken from 200 to 300$\mu$s to clear each interrupt.

Each DSP has available to it information about trigger conditions on other strings in the system. The first DSP to recognize an interesting global trigger condition, combining its own information with that from other strings, collects data from all strings and interrupts a crate-resident Motorola 68040 microcomputer, level three of the system. This computer handles communications with the host, and has the capability of applying additional conditions on the data if the trigger rate at this level gets too high. Non-track trigger conditions are also flagged at this level of the system.

The 68040 passes data via an Ethernet network to the fourth level of the system, a SUN SPARCstation 2. This host is networked to other computers that monitor the undersea environment and perform control functions. It also serves as master control for the system, downloading software and the parameters that define the trigger into the processors on the lower levels of the system. It performs similar functions with regard to the undersea elements of the logic.

The host may or may not try a preliminary track fit before archiving the data on a disk file. Ultimately, data will be distributed to DUMAND collaborators on 8mm tape cassettes. Data and the operating status of the system will also be monitored at collaborators' home institutions via the worldwide HEPNET communications network.

## REFERENCES

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